Improved colour decorrelation for lossless colour image compression using the LAR codec

François Pasteau, Clément Strauss, Marie Babel, Olivier Déforges, Laurent Bédat

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François Pasteau, Clément Strauss, Marie Babel, Olivier Déforges, Laurent Bédat

IETR/Image group Lab
CNRS UMR 6164/INSA Rennes
20, avenue des Buttes de Coësmes
35043 RENNES Cedex, France
{fpasteau, cstrauss, mbabel, odeforge, lbedat}@insa-rennes.fr

ABSTRACT

Next generations of still image codecs should not only have to be efficient in terms of compression ratio, but also propose other functionalities such as scalability, lossy and lossless capabilities, region-of-interest coding, etc. In previous works, we have proposed a scalable compression method called LAR, for Locally Adaptive Resolution, that covers these requirements. In particular, the Interleaved S+P scheme offers an efficient mean to compress images. In this paper, three modifications of this coder are proposed to extend its capabilities to the lossless coding of colour images. Firstly, decorrelation of the image components is introduced by using reversible colour transforms. Secondly, an adaptive decorrelation of the components is introduced. Finally, a classification between the image components is introduced. Results are then discussed and compared to the state of the art, thus revealing high compression performances of our coding solution.

1. INTRODUCTION

Despite many drawbacks and limitations, JPEG is still the most commonly-used compression format in the world. JPEG2000 overcomes this old technique, particularly at low bit rates, but at the expense of a significant complexity overhead. Therefore, the JPEG normalization group has recently proposed a call for proposals on JPEG-AIC (Advanced Image Coding) in order to look for new solutions for still image coding techniques [1]. Its requirements reflect the earlier ideas of Amir Said [2] for a good image coder: compression efficiency, scalability, good quality at low bit rates, flexibility and adaptability, rate and quality control, algorithm unicity (with/without losses), reduced complexity, error robustness (for instance in a wireless transmission context) and region of interest decoding at decoder level. Additional functionalities such as image processing at region level, both at the coder or the decoder could be explored. The LAR (Locally Adaptive Resolution) tries to address all these features. In [3], we proposed an original scheme able to perform efficient lossy compression, enabling an unusual hierarchical region representation (without any shape description). Then, in [4], we presented an extension of a more efficient scalable multi-resolution solution in terms of both lossy and lossless compression, the LAR Interleaved S+P. New improvements have been shown by the introduction of the Reversible Walsh Hadamard Transform (RWHaT) in [5].

The work in this paper is based on the Interleaved S+P scheme and has been designed to produce a better compression ratio in lossless coding of colour images. A critical application of lossless coding of colour images concerns cultural digital libraries [6]. Museums actually try to safely digitalize their belongings and thus produce large quantities of lossless colour pictures. In France, the national TSAR project has been created to develop an efficient mean to compress and secure high resolution images in collaboration with the Louvre museum [7]. Current digital cameras are wide spread and generate high resolution colour images. Professional photographers tend to prefer lossless compression of their pictures to avoid artifacts due to image compression.

The use of the Interleaved S+P coding scheme has been motivated by its efficiency. This coder has been proved to produce far better results than the state of the art. It also offers interesting features such as scalability or Quadtree partitioning. However, the compression efficiency for colour images can be greatly increased by the mean of classification or/and decorrelation of the components as described here. Image compression schemes are often developed only for gray scale images and directly applied on the three components of colour images. However, image coders such as JPEG 2K have shown that using the correlation between components can give better compression ratio.

The paper is organised as follows. The following section introduces the basic of the LAR coder and the Interleaved S+P scheme. In section 3, decorrelation using reversible colour transform is presented followed in section 4 by an adaptive component decorrelation. In section 5 a classification of the components is proposed. Finally, in section 6, results of the different schemes are shown and discussed.

2. LAR INTERLEAVED S+P

2.1 LAR overview

The basic concept of the LAR method is that local resolution should be adapted to suit local activity. Also assuming that an image consists of global information and local texture, we firstly proposed a two-layer, content-based codec, both relying on a Quadtree partition. The first layer, called the FLAT LAR, encodes the global information at block level representation. The additional second layer enables texture compression within blocks. Therefore, the method provides natural SNR scalability. The block sizes are estimated through a local morphological gradient. The direct consequence is that the smallest blocks are located round the edges whereas large blocks map homogeneous areas. This being so, the main feature of the FLAT coder consists of preserving contours while smoothing homogeneous parts of the image. This characteristic is also exploited to get a free hierarchical region representation: from the low bit-rate image compressed by the FLAT LAR, both coder and decoder can perform a segmentation process by iteratively merging blocks into regions. A direct application is then Region Of Interest (ROI) enhancement, by first selecting regions at coder or decoder and enabling second layer coding only for the relevant blocks.

In order to obtain higher image quality, the texture (whole error image) can be encoded by the second layer called spectral coder that uses a DCT adaptive block-size approach. The use of adapted square size allows a content-based scalable encoding scheme: for example, edge enhancement can be made by only transmitting the AC coefficients of small blocks.

2.2 Interleaved S+P

To perform the decorrelation of the picture, the interleaved S+P scheme is used. The S+P transform (S-transform + Prediction) is based on the 1D S-transform applied on the 2 vectors formed by 2 diagonally adjacent pixels in a 2x2 block as depicted in figure 1. Let z_0 and z_1 denote the S-transformed coefficients and (u_0, u_1) be the couple of values, we have:

$$\left| \begin{array}{l} z_0 = \lfloor (u_0 + u_1)/2 \rfloor, \\ z_1 = u_1 - u_0. \end{array} \right. \qquad (1)$$

The prediction is achieved in 3 successive passes. If $i \in \{0, 1\}$ and $k \in \{1, 2, 3\}$, z_i^k constitutes the z_i coefficient coded through the k^{th} pass. Let I be the original image of size $N_x \times N_y$. The multiresolution representation of an image is described by the set $Y_{l l=0}^{lmax}$, where l_{max} is the top of the pyramid and l = 0 the full resolution image. Four blocks $\frac{N}{2} \times \frac{N}{2}$ are gathered into one block $N \times N$ valued by the average of the two blocks of the first diagonal (first S-pyramid in Fig. 2) The transformation of the second diagonal of a given 2×2 block can also be seen as a second S-pyramid, where the pixel values depend on the ones existing at the lower level of the first S-pyramid. Interleaving is in this way realised. When using the Interleaved S+P scheme, z_0^1 coefficients

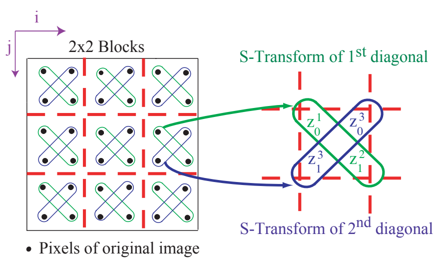


Figure 1: S-Transform scheme

of a given layer are automatically retrieved from the upper layer. That is why only three types of coefficients z_1^2, z_0^3 and z_1^3 have to be estimated for each level. This estimation leads to three different types of errors, each corresponding to one type of coefficients. The first layer coding (FLAT LAR) builds the first pass of the pyramid used by the Interleaved S+P. It decomposes each pixel of a given layer into a 2×2 block into a lower level according to the information given by the Quadtree. To perform lossless compression, the second layer coding (texture) performs a second pass on this pyramid. It decomposes every pixel that have not been decomposed previously.

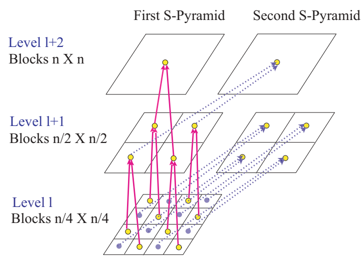


Figure 2: S pyramid scheme

The LAR coder has been initially developed to compress gray scale picture. However, as a colour can be represented by three components (e.g. Red, Green, Blue), this scheme can be applied on each component and can thus perform colour image compression. The next section presents three different colour spaces that can be used for colour image compression.

3. IMPLEMENTATION OF REVERSIBLE COLOUR SPACE

To perform lossless colour compression, a reversible colour space is needed. Such a colour space has a reversible transform that prevents data loss during colour space transformation. As shown in figure 3, this transformation is done before the Interleaved S+P scheme. In this section, three different reversible colour spaces are introduced and their transformation from Red Green Blue (RGB) colour space are presented.

3.1 YCoCg-R colour space

YCoCg-R is an extension of the YCoCg colour transform [8] with the particularity of having a reversible transform. Equations 2 and 3 are respectively determining the RGB to YCoCg-R and inverse YCoCg-R to RGB transforms,

$$\left| \begin{array}{l} Co = R - B \\ t = B + (Co >> 1) \\ Cg = G - t \\ Y = t + (Cg >> 1) \end{array} \right. \qquad (2)$$

$$\left| \begin{array}{l} t = Y - (Cg >> 1) \\ G = Cg + t \\ B = t - (Co >> 1) \\ R = B + Co \end{array} \right. \qquad (3)$$

where >> is the right arithmetic shift operator.

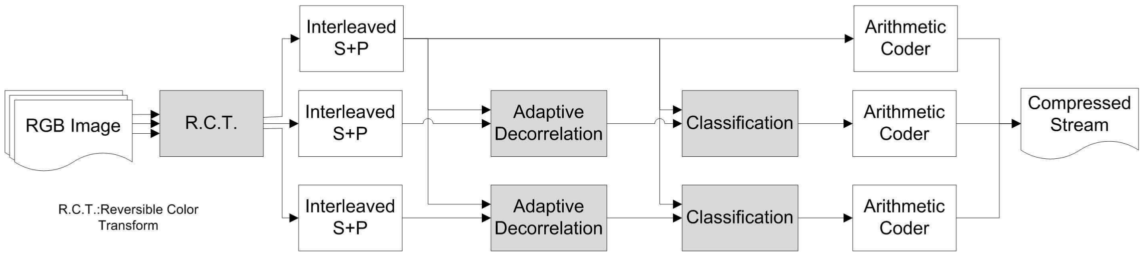


Figure 3: Lossless colour compression extension of LAR coder

This reversible colour transform benefits from a low complexity as the implementation requires only bit-shifts and additions. YCoCg-R gives a direct access to the luminance component of the picture. A Microsoft patent restricts the use of this colour space. Therefore its implementation in a final product is more difficult. The results given here are only shown as a reference.

3.2 O1O2O3 colour space

The O1O2O3 colour space has a good compression efficiency [9]. Equations 4 and 5 are respectively determining the RGB to O1O2O3 and O1O2O3 to RGB transforms.

$$\left| \begin{array}{l} O1 = \lfloor \frac{R+G+B}{3} + 0.5 \rfloor \\ O2 = \lfloor \frac{R-B}{2} + 0.5 \rfloor \\ O3 = B - 2G + R \end{array} \right. \tag{4}$$

$$\left| \begin{array}{l} B = O1 - O2 + \lfloor \frac{O3}{2} + 0.5 \rfloor - \lfloor \frac{O3}{3} + 0.5 \rfloor \\ G = O1 - \lfloor \frac{O3}{3} + 0.5 \rfloor \\ R = O1 + O2 + O3 - \lfloor \frac{O3}{2} + 0.5 \rfloor - \lfloor \frac{O3}{3} + 0.5 \rfloor \end{array} \right. \tag{5}$$

The study of this colour transform has been motivated by its good correlation with the Human Visual System. However, its implementation is very complex as it requires division by 3. Furthermore, O1, O2 and O3 components cannot be directly used to retrieve the luminance component.

3.3 YDbDr colour space

The YDbDr colour space is the reversible colour transform used in JPEG 2000 image codec. Equations 6 and 7 are respectively determining the RGB to YDbDr and YDbDr to RGB transforms.

$$\begin{bmatrix} Y \\ Db \\ Dr \end{bmatrix} = \begin{bmatrix} 1/4 & 1/2 & 1/4 \\ 1 & -1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 3/4 & -1/4 \\ 1 & -1/4 & -1/4 \\ 1 & -1/4 & 3/4 \end{bmatrix} \begin{bmatrix} Y \\ Db \\ Dr \end{bmatrix} \tag{7}$$

This colour space features a low complexity as it requires only shift and addition operators to be calculated. Furthermore, the luminance component Y of the picture is directly accessible. Its computation is really fast on a camera using Bayer filter to retrieve colours.

These three colour spaces have been implemented in the LAR codec. They perform an initial decorrelation between the components of a colour image before applying the Interleaved S+P scheme. This decorrelation can be further improved by the mean of an adaptive inter-component decorrelation presented in the next section.

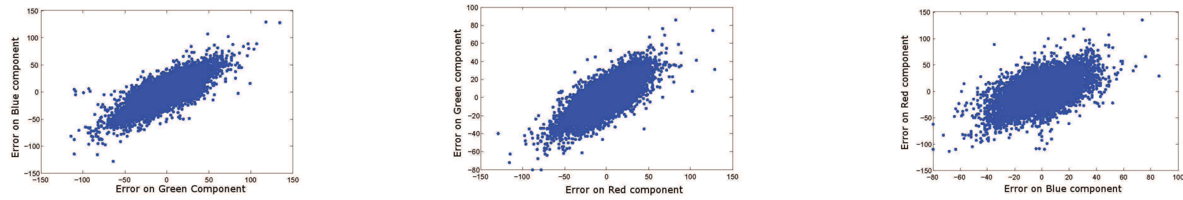
4. ADAPTIVE INTER-COMPONENT DECORRELATION

Adaptive inter-component decorrelation is used directly after the Interleaved S+P scheme, as shown on figure 3. Figure 4 presents the correlation between R,G and B error images of the Interleaved S+P coding of "lena". Each dot corresponds to a pixel of the image with its coordinates being Red, Green or Blue values of this pixel. An important correlation can be observed between Red, Green and Blue components. Adaptive inter-component decorrelation uses this residual correlation. In case of highly correlated space colour such as RGB, a direct linear relation between components can be extrapolated. This scheme predicts error values of one component from error values of another using linear coefficients. Coefficients are computed for a small set of equally distributed points to keep a low complexity of implementation. Those coefficients can be easily and accurately computed in the case of a well correlated colour space. However, for decorrelated components such as YDbDr, O1O2O3 or YCoCg-R, inter component classification might be preferred. This classification is proposed in the next section and can be used together with the Adaptive inter-component decorrelation.

5. INTER-COMPONENT CLASSIFICATION

An inter-component classification similar to the classification presented in [10] is performed after the Interleaved S+P scheme as shown on figure 3. Conditional entropy theory is used to improve the coding efficiency of the overall compression scheme. Its development has been motivated by the residual correlation existing between the error images coming from Interleaved S+P scheme. In figure 5 similarities can be observed between error images coming from the Interleaved S+P coding of "lena" picture in RGB colour space. Actually contours are more prone to have high error values whereas homogeneous areas produce low error values. Those areas tend to be the same between the different image components.

As the z_1^2, z_0^3 and z_1^3 coefficients present different characteristics in terms of error distribution, the inter



a) B/G *b) G/R* *c) R/B*

Figure 4: Error image correlation between RGB components of lena image

a) Red *b) Blue* *c) Green*

Figure 5: Error images of RGB components of lena image

component classification scheme is performed independently for each type of error. It leads to three different types of classification for both FLAT LAR and Texture. The aim of such context modeling is to perform discriminations inside each type of errors. Thus, coefficients of a given type producing the same error distributions are gathered into one context class.

The proposed Inter-chrominance Classification is performed according to the following algorithm. Let P_i be the i^{th} pixel of the image P and (P_i) its value. Let C_1, C_2 and C_3 be the three classes of the classification.

1. One of the three error images realised from the components is used as a reference Ref to code the other two $P1$, $P2$, Ref is not modified.
2. Histogram of absolute values of (Ref) is computed.
3. A first error threshold $T1$ is determined according to the histogram mean.
4. A second error threshold $T2$ is determined according to the 3/4 of the histogram population.
5. For each pixel $P1_i$ and $P2_i$ of each other component, the value of the error R_i located at the same position in the reference image is extracted.
6. $C_1 = \{P1_i \cup P2_i \mid abs((Ref_i)) < T1\}$.
7. $C_2 = \{P1_i \cup P2_i \mid T1 \leq abs((Ref_i)) < T2\}$.
8. $C_3 = \{P1_i \cup P2_i \mid T2 \leq abs((Ref_i))\}$.

6. RESULTS

A preliminary set of three pictures has been used to evaluate the performances of the proposed solution. This set includes peppers , mandrill and lena pictures (Table 1). Each of them has different characteristics: mandrill image has high frequencies whereas peppers image features large areas of identical colour. Finally Lena has both high frequencies and low frequencies respectively located in her hair and on the background. To obtain comparable results with other image coders such as JPEG2K, a simple arithmetic coder has been used. Except for peppers picture, performing colour space decorrelation improves compression results. The YCoCg-R, O1O2O3 and YDbDR colour spaces offer an average 4% gain on mandrill picture and an average 2.5% gain on lena image. The specificity of peppers on colour spaces is due to the fact that this image has mainly two predominant colours, red and green. Therefore RGB colour space can, in this particular case, lead to better results.

Adaptive inter component decorrelation improves the compression ratio for all images and colour spaces. The most significant improvements are realised with RGB colour space. RGB being the most correlated colour space used in this work, adaptive inter component decorrelation can be more accurate and result in even better compression gain. Inter component classification leads also to better compression ratios for all images and all colour spaces. It even outperforms the adaptive decorrelation in few cases such as peppers picture with YCgCo-r and O1O2O3 colour spaces. However, in most cases, this classification is still less efficient than the adaptive inter component decorrelation, especially on the RGB colour space. Inter component classification can be used in addition with adaptive inter component decorrelation. For all images and colour spaces, compression results obtained with such schemes are improved when compared to the adaptive decorrelation and the classification used independently. These schemes used together lead to improvements especially for the RGB colour space with 0.3, 0.97 and 0.71 bpp gains respectively for peppers, mandrill and lena pictures. Finally, for all images, the best compression scheme in terms of compression ratio is obtained with RGB colour space and both adaptive inter component decorrelation and inter component classification. However to obtain better scalability, YDbDr colour space might be preferred due to its ability to directly retrieved the luminance.

When compared to the state of the art compression scheme JPEG2K, compression results obtained with the Interleaved S+P scheme, decorrelation and classification are better with each colour space. When using the RGB colour space, 0.32, 0.20 and 0.46 bpp gain can be observed respectively on peppers, mandrill and lena.

7. CONCLUSION

The Interleaved S+P scheme leads to interesting results for gray scale images. Therefore an extension of this scheme has been proposed here for lossless colour compression aiming at good performance. Firstly, three re-

peppers	Alone	Decorrelation	Classification	Dec.+Classif.
YCoCg-R	14.975	14.911	14.898	14.838
O1O2O3	14.968	14.919	14.896	14.854
YDbDr	15.048	14.938	14.960	14.866
RGB	14.907	14.673	14.767	**14.598**
			JP2K	14.920

mandrill	Alone	Decorrelation	Classification	Dec.+Classif.
YCoCg-R	18.170	18.090	18.121	18.053
O1O2O3	18.106	18.067	18.065	18.023
YDbDr	18.122	18.033	18.084	17.986
RGB	18.948	18.012	18.705	**17.974**
			JP2K	18.176

lena	Alone	Decorrelation	Classification	Dec.+Classif.
YCoCg-R	13.582	13.359	13.437	13.269
O1O2O3	13.536	13.368	13.392	13.265
YDbDr	13.577	13.305	13.422	13.218
RGB	13.914	13.291	13.662	**13.207**
			JP2K	13.669

Table 1: Compression results in bpp after LAR compression of peppers, mandrill and lena.

versible colour spaces have been introduced and compared in terms of scalability and complexity. An inter component adaptive decorrelation has been presented to improve the decorrelation after the Interleaved S+P scheme using information between the image components. An inter component classification has been proposed to improve compression ratio for decorrelated components. Compression results obtained with all those modifications have been presented and gains from 0.20 to 0.46 bpp has been observed. Using both inter component adaptive decorrelation and inter component classification gives the best compression results for all colour spaces. Considering colour spaces, using the RGB colour space with the presented decorrelation and classification leads to the best compression results. However, for better scalability, YDbDr colour space might be considered.

Results have been shown on a small set of images, therefore work is being done on high definition images coming from Thomas Richter database [11] to evaluate the performance of this algorithm on higher definition.

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